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BURLINGTON
ENVIRONMENTAL

PUMPING TEST WORK PLAN
FOR RCRA FACILITY INVESTIGATION
BURLINGTON ENVIRONMENTAL INC.
PIER 91 FACILITY
SEATTLE, WASHINGTON

November 1993

Prepared for:

Burlington Environmental Inc.
Seattle, Washington

Project 624878

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Revision 2

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1 PUMPING TEST SUMMARY

This section summarizes the purpose, objectives, schedule, and scope for the proposed pumping test.

1.1 Background and Purpose

This work plan outlines the pumping test proposed for the Burlington Environmental Inc. (Burlington) Pier 91 facility, as part of the RCRA Facility Investigation (RFI) to be conducted at that facility. An RFI Work Plan (Burlington, April 1992) for the Pier 91 facility was conditionally approved by the U.S. Environmental Protection Agency (USEPA) in July 1992 (USEPA, 1992). One of the conditions that the USEPA imposed as a requirement for final approval of the RFI Work Plan was that Burlington submit plans for the proposed pumping test. To satisfy that requirement, and to provide a basis for conducting the pumping test, Burlington submitted a pumping test work plan to the USEPA in October 1992 (Burlington, October 1992). After discussions were held between representatives of Burlington and the USEPA in December 1992, the USEPA submitted written comments on the work plan to Burlington (USEPA, 1993). A revised work plan (revision 1) addressing those comments was submitted to EPA in April 1993. In October 1993, Burlington received comments from EPA on the April 1993 revised work plan. In response to these comments, and as a result of a meeting between Burlington and EPA on November 3, 1993, Burlington has revised this work plan a second time (revision 2). This work plan, if approved, will become an addendum to the existing RFI Work Plan.

1.2 Objectives

The objectives of this pumping test are as follows:

- to infer the degree of hydraulic connection between the upper and lower water-bearing zones through the silty sand layer;
- to assess the hydraulic properties of the deep aquifer; and
- to check the consistency of other available hydraulic information, such as slug test results and laboratory permeability measurements.

1.3 Scope

The testing described in this work plan will be conducted in two parts: a brief step-drawdown test, followed by a constant-discharge pumping test. A detailed description of the scope of this work is given in the following sections. In summary, the scope includes the following elements:

- data collection;
- data analysis; and
- reporting.

The data collection element involves the acquisition of various types of data at selected time intervals throughout the test. Pertinent data include barometric pressure, tide levels, and groundwater levels. The data analysis element primarily involves the interpretation of the pumping test data, and their integration with hydraulic and stratigraphic data collected during previous site investigations, and other ongoing RFI activities. The reporting element involves the description of test procedures and analysis methods, summary of data and analysis results, and discussion of the results and conclusions.

1.4 Schedule

The field activities of the pumping test will be conducted following the installation and development of monitoring wells CP-106B, CP-122A and CP-122B. This timing is necessary because these wells, in addition to existing monitoring well CP-106A, are to be used for pumping or water-level observations during the test.

There will be a minimum 24-hour waiting period between the completion of certain types of field activities (e.g., drilling, well installation and development, and slug testing), and the initiation of the pumping test. This waiting period is intended to minimize unknown disturbances of the groundwater levels in the area prior to the test. Such disturbances could complicate the interpretation of the pumping test data.

The RFI Work Plan (Burlington, April 1992) calls for laboratory permeability testing of samples from the silty sand layer. This schedule is intended to allow Burlington to interpret the pumping test data after the results of the proposed permeability testing are available.

The pumping test will be performed after the initial session of the proposed tidal monitoring has been completed. The response of groundwater levels to tidal forcing, if not accurately accounted for, may partially or fully mask the response to deep-aquifer pumping. This might render the test useless, or at least require reinterpretation following completion of the tidal monitoring study. Therefore, it is prudent to interpret the pumping test data following the evaluation of tidal effects on the deep aquifer.

2 TEST DESCRIPTION

2.1 General Procedures

2.1.1 Step-Drawdown Test

Prior to the constant-discharge pumping test, a step-drawdown test will be performed. The purpose of the step-drawdown test is to assist in the selection of an appropriate discharge rate and duration for the constant-discharge pumping test. The step-drawdown test will be conducted in two periods, a drawdown period followed by a recovery period. The water level in the pumping well (CP-122B) will be monitored throughout both periods.

During the drawdown period, groundwater will be pumped out of the deep-aquifer well CP-122B. The drawdown period will consist of at least three stages or steps. The pumping rate will be held constant throughout each step, at a value that exceeds the rate used in the previous step. The duration of each step shall be sufficient for a graph of water level versus logarithm of time to fall approximately on a straight line.

The recovery period will begin at the end of the last step of the drawdown period. The pump will be shut off at the start of the recovery period, and will remain off throughout the period. The water level in the pumping well will be allowed to recover until the drawdown is less than or equal to 10 percent of the maximum drawdown observed during the test.

Water levels used to evaluate both the recovery after pumping and the stabilization during pumping will be corrected for barometric pressure changes and for tide-induced water-level changes.

2.1.2 Ambient Monitoring

Following completion of the step-drawdown test (including the recovery period), and prior to the start of the constant-discharge pumping test, water levels in selected wells will be monitored regularly. The purpose of this monitoring period is to assess temporal trends in ambient water levels. The duration of this ambient monitoring period will be at least 24 hours. Precautions will be taken to avoid disturbing the groundwater system during this period. For instance, no pumping or hydraulic testing will be conducted at this time. The wells to be monitored include CP-106A, CP-106B, CP-122A, and CP-122B.

2.1.3 Constant-Discharge Test

The constant-discharge test will involve a drawdown period during which water is pumped at a constant rate out of the deep-aquifer monitoring well CP-122B, followed by a recovery period of approximately equal duration, in which no pumping occurs. Water levels in wells CP-106A, CP-106B, CP-122A, and CP-122B will be measured and recorded throughout both periods.

The duration of the drawdown period is expected to be approximately 48 hours. Ideally, the aquifer should be pumped until steady-state is reached. However, in many cases (primarily in unconfined aquifers), steady state conditions are never attained. The lower aquifer at the site is expected to behave as a confined or a leaky aquifer. Typical pumping durations for reaching steady state in these types of aquifers range from 15 to 20 hours for a leaky aquifer and average about 24 hours for a confined aquifer. Therefore, 48 hours of pumping should be more than adequate to reach steady state. Practical considerations limit the drawdown period to a maximum of 72 hours. Such considerations include the on-site water storage capacity, water testing and disposal cost, and test operating costs. Attaining steady state during pumping tests is not critical for calculating hydraulic properties. Solutions and models have been developed to calculate aquifer parameters under transient conditions. However, it is always good practice to strive for steady state when conducting pumping tests.

To assess if steady state has occurred during pumping, time-drawdown plots for each observation well will be constructed on a semi-log scale. When time-drawdown data for each observation well approximate a straight line and are parallel with one another, steady state conditions have been attained. If, at this point the pumping duration has exceeded 48 hours, pumping will cease. However, the pumping duration will be a minimum of 48 hours.

The target pumping rate is that pumping rate that will cause the drawdown in the pumping well to be equal to the target drawdown (defined below) at the end of the drawdown period. The target pumping rate depends on the following:

- aquifer transmissivity;
- aquifer storage coefficient;
- presence, geometry, and type, of hydrogeologic boundaries; and
- efficiency of the pumping well.

Data collected during the step-drawdown test will be analyzed to determine the target pumping rate for the constant-discharge test. The target-rate selection procedure is described in Section 4.1. The target rate is anticipated to be approximately five gallons per minute.

The target drawdown is the maximum drawdown that could be practically attained in the pumping well. In the case of well CP-122B, the maximum drawdown is the difference in elevation between the initial corrected water level in the well and the top of the confined aquifer at this location. The water level in well CP-122B was approximately 4.92 feet below the top of casing on March 8, 1993. This is the most recent water level datum available. The top of casing is less than one foot below ground surface. The preliminary geologic log from this borehole suggests that the top of the aquifer lies approximately 38.5 feet below ground surface. By subtraction, the available drawdown is approximately 32.6 feet.

This calculation assumes that tide-induced water-level fluctuations in the well are negligible in comparison to the total available drawdown. Preliminary results from the first tidal monitoring session, which was conducted on March 4-8, 1993, support this assumption. This calculation also assumes that the pump intake port is set below the top of the confined aquifer during the test. If the pump is set higher in the well, there will be a corresponding reduction in the available drawdown.

A pumping rate that is lower than the target rate will result in a lower-than-target drawdown, and consequently a lower signal-to-noise ratio for the water-level data collected during the test. A pumping rate that is higher than the target rate may result in excessive drawdown and subsequently lead to one or more of the following undesirable conditions:

1. The water level in the pumping well is lowered below the upper boundary of the confined aquifer, thus altering the hydrogeologic state of the aquifer from confined to unconfined. This might severely complicate interpretation of the test results.

2. The pump is damaged or destroyed (e.g., due to overheating).

3. The pumping rate can no longer be maintained, because it exceeds the yield of the well.

If any one of these conditions occurs, pumping will have to be ceased immediately, thus limiting the duration of the drawdown period during which valuable water-level data are collected.

2.2 Decontamination

All equipment to be lowered into monitoring wells will be decontaminated according to the procedures specified in the RFI Work Plan (Burlington, April 1992). Such equipment includes:

- submersible pump housing, power cable and suspension line;
- pump discharge hose and pump/hose fitting;
- oil/water interface detector (probe and cable);
- electronic water-level indicator (probe and cable); and
- pressure transducer housings and cables.

2.3 Disposal of Discharge Water

Water discharged from the pumping well will be conveyed, via pipes and/or hoses, to an on-site tank trailer or holding tank prior to disposal. The water will be managed as a wastestream, as per Burlington's standard operating procedures, prior to treatment and/or discharge at one of the Burlington treatment, storage, and disposal (TSD) facilities.

3 DATA COLLECTION

Subsections 3.1 through 3.4 outline efforts to collect data during field activities associated with the pumping tests. Section 3.5 describes relevant data to be obtained from other sources.

3.1 Groundwater Levels

Water levels in wells will be measured using submersible pressure transducers. One pressure transducer will be dedicated to each of the monitored wells. The measurements will be made and recorded at preprogrammed time intervals using an electronic data logger. For the ambient monitoring period, the water level in each well will be measured once every 10 minutes. For each step of the step-drawdown test, and for the drawdown period of the constant-discharge test, the time intervals for water-level measurement will correspond to the following schedule.

Log Cycle	Elapsed Time	Time Interval
1	0-5 seconds	0.5 second
2	5-20 seconds	1 second
3	20-120 seconds	5 seconds
4	2-10 minutes	0.5 minute
5	10-100 minutes	2 minutes
6	>100 minutes	10 minutes

In this table, "Elapsed Time" refers to the time elapsed since the beginning of the step or period. This schedule will also be followed during the recovery periods of both the step-drawdown and constant-discharge tests.

In addition, the water levels in the wells will be measured periodically and recorded using one or more electronic water-level indicator(s). Measurements made with the water-level indicator(s) can be used as a check for the electronic data acquisition system, and may be used for backup in case of equipment failure.

3.2 Barometric Pressure

Barometric pressure will be measured and recorded hourly throughout the step-drawdown test, the ambient monitoring period, and the constant-discharge test, using either a portable barometer or a barometric pressure transducer with an electronic data logger.

3.3 Volumetric Discharge Rate

For the aquifer tests described here, it is important to keep the discharge rate of the pump constant throughout the entire step or drawdown period. Variable discharge rates are difficult to monitor, complicate data interpretation, and may even render test results useless.

The discharge rate of the pump will be estimated and recorded periodically throughout the drawdown period of each test. The pump system will be adjusted as necessary to keep the discharge rate constant in time and close to the target value. The discharge rate will be estimated by using a totalizing water meter and by measuring the amount of time that is required to fill a calibrated container, such as a plastic bucket, with the water stream that is discharged from the pumping well. The discharge will be measured where the outlet line from the pumping well enters the holding tank, so that the estimate is not biased by head loss differences.

3.4 Tide Level

Tide levels will be measured and recorded at half-hour intervals for the duration of the pumping test. The tide levels will be measured from Pier 91 in Elliot Bay, as close to the Burlington facility as practical. Data will be collected using a pressure transducer placed in a stilling tube secured to the side of the pier. Tide data will be collected beginning 24 hours prior to the ambient monitoring period, and ending after the recovery phase of the constant discharge test.

3.5 Other Data

Interpretation of the pumping test data discussed above will be facilitated by examination of additional site data. Potentially useful data from sources other than the pumping test include information from previous investigations and from other RFI activities. Relevant information collected during previous investigations includes the following (Sweet-Edwards/EMCON, Inc.; 1988, 1989):

- stratigraphic information;
- results of slug tests conducted in monitoring wells; and
- groundwater system tidal response data.

Relevant information to be collected through planned RFI activities includes the following:

- stratigraphic information collected during drilling of new monitoring wells;
- results of slug tests conducted in new monitoring wells;
- results of laboratory permeability testing of samples from the silty sand layer at the locations of the new deep wells; and
- results of the tidal monitoring program.

All of the activities that generate these data are to be conducted as part of the RFI and the test procedures and methods are described in the RFI Work Plan (Burlington, April 1992).

4 DATA ANALYSIS

4.1 Corrections for Barometric and Tidal Effects

An attempt will be made to differentiate the effect of pumping from other effects on groundwater levels in the deep aquifer. These other effects include the observed barometric pressure fluctuations, tide level fluctuations, and temporal trends in ambient groundwater levels. Calculations for this purpose will be based on the assumption that the aquifer's response to each of these effects is independent of the others. That is, the effects are assumed to be additive:

$$h_{meas,i}(t) = h_{ambi,i}(t) - s_i(t) + h_{baro,i}(t) - h_{tide,i}(t)$$

where

t = time

$h_{meas,i}(t)$ = measured water level at monitoring point i and time t

$h_{ambi,i}(t)$ = ambient water level at monitoring point i and time t

$s_i(t)$ = drawdown at monitoring point i and time t due to pumping

$h_{baro,i}(t)$ = barometric component of water-level fluctuation at monitoring point i and time t

$h_{tide,i}(t)$ = tidal component of water-level fluctuation at monitoring point i and time t.

In the equation above, the ambient water level is that water level that would be measured if there were no barometric pressure fluctuations, no tide-level fluctuations, and no pumping. This approach is consistent with that presented by Kruseman and de Ridder (1992). Solving this equation for the drawdown gives the following:

$$s_i(t) = h_{ambi,i}(t) - h_{meas,i}(t) + h_{baro,i}(t) - h_{tide,i}(t)$$

This relationship will be used to estimate the drawdown at the monitoring points. Ambient water levels will be estimated using water-level data from the ambient monitoring period following the step-drawdown test.

Water-level fluctuations caused by barometric pressure changes are assumed to obey the following conditions:

- the aquifer behaves as a perfectly elastic body, so that it responds instantaneously to barometric pressure fluctuations;
- due to the elastic nature of the aquifer, water-level fluctuations associated with barometric pressure fluctuations are directly proportional to such fluctuations;
- the proportionality factor is a constant that depends on the hydromechanical properties of the deep groundwater system; and
- the proportionality factor may vary seasonally (e.g., due to seasonal variations in loading caused by seasonal water-level variations in the shallow aquifer), but does not vary over the duration of the pumping test.

In summary, for relatively small changes in the total applied stress on the aquifer, such as those caused by changes in barometric pressure, the aquifer response is expected to be approximately elastic. Therefore the barometric component of the observed water-level fluctuations will be estimated as follows:

$$h_{baro,i(t)} = E_{baro,i} \times H_{baro}(t)$$

where

$E_{baro,i}$ = estimated barometric efficiency of the aquifer, at monitoring point i

$H_{baro}(t)$ = measured atmospheric pressure fluctuation, at time t, expressed in terms of equivalent head of pure fresh water.

Freeze and Cherry (1979) define the barometric efficiency of an aquifer as the ratio of the magnitude of barometrically induced water-level fluctuations to the magnitude of the simultaneous barometric pressure fluctuations (expressed in terms of equivalent head of pure fresh water):

$$E_{baro,i} = |h_i(t)|/|H_{baro}(t)|$$

where

$|h_i(t)|$ = amplitude of barometrically-induced water-level fluctuation at monitoring point i and time t

$|H_{baro}(t)|$= amplitude of barometric pressure fluctuation at time t.

The barometric efficiency of each of the monitoring points utilized in the pumping test will be estimated using the above formula and water-level data collected during the first of the two planned tidal monitoring sessions.

The tidal component of the observed water-level fluctuations will be estimated based on the following assumptions:

- the tidal component of the observed water-level fluctuations is directly proportional to fluctuations in the tide level of Elliott Bay, lagged by some time value;

- the proportionality factor is a constant that depends on the hydromechanical properties of the deep groundwater system;

- the time lag is a constant that depends on the hydromechanical properties of the deep groundwater system; and

- the proportionality factor and the time lag may vary seasonally, but do not vary over the duration of the pumping test.

Based on these assumptions, the tidal component of the observed water-level fluctuations will be estimated as follows:

$$h_{tide,i}(t) = 0.01 \times E_{tide,i} \times H_{tide}(t-t_i)$$

where

$E_{tide,i}$ = estimated tidal efficiency of the aquifer at monitoring point i

$H_{tide}(t)$ = measured tide-level fluctuation at time t, expressed in terms of equivalent head of pure fresh water

t_i = estimated tidal time lag at monitoring point i.

Definitions and procedures for estimating the tidal efficiency and time lag are presented in the Tidal Monitoring Work Plan (Burlington, 1993).

4.2 Analysis of Step-Drawdown Test Data

The purpose of the step-drawdown test is to infer the target pumping rate for the constant-discharge test. This will be accomplished using the following procedures:

1. The drawdown in the pumping well, from the drawdown portion of the step-drawdown test will be plotted, versus the logarithm of elapsed time. Also, the pump discharge rate versus logarithm of time will be plotted. The plots will be visually inspected to detect anomalies.

2. The drawdown data will be corrected for barometric and tidal effects, using the procedures described in Section 4.1. Temporal variations in ambient water levels during the step-drawdown test will be assumed negligible.

3. The corrected drawdown data will be plotted versus the logarithm of elapsed time. The plot will be visually inspected to detect anomalies. The corrected data will be used for the remaining data analysis procedures.

4. For each step of the step-drawdown test, the following will be completed:

   (a) The drawdown curve will be projected (extrapolated) forward in time, beyond the end of the step, thus estimating the drawdown that would have been observed if there had been no subsequent pumping rate increases. This curve will be referred to as the projected drawdown curve for the step.

   (b) The projected drawdown corresponding to the time value

   $$t' = t_{i-1} + t_D$$

   will be read off the curve, where

   t_{i-1} = time at the end of the previous step of the step-drawdown test.

t_D = estimated duration of the drawdown period of the planned constant-discharge test.

Designate this projected drawdown s_i.

(c) The projected drawdown corresponding to time t' (defined above) will be read from the previous step's projected drawdown curve. Designate this drawdown value by s_{i-1}.

(d) The incremental drawdown for the ith step will be calculated as

$$ds_i = s_i - s_{i-1}$$

and the adjusted drawdown for the ith step as

$$s_i^* = \sum_{m=1}^{i} ds_m$$

(e) Procedures (a) through (d) will be repeated for each step of the step-drawdown test, tabulating the ordered pairs of discharge/adjusted drawdown values (Q_i, s^*_i) (i = 1, 2, ..., N, where N is the total number of steps in the step-drawdown test and Q^i is the pump discharge rate during the ith step).

5. The N ordered pairs of discharge/adjusted drawdown values tabulated in procedure (4)(e) will be plotted. A curve will be sketched through the data points. Refer to this plot as the discharge-versus-adjusted-drawdown plot. Ideally, the curve should pass through the origin ($Q = 0$, $s^* = 0$).

6. The target discharge rate for the constant-discharge test will then be selected as follows. On the drawdown axis of the discharge-

> versus-adjusted-drawdown plot, that point corresponding to the known target drawdown value will be located. Recall that in the present case the target drawdown value was estimated to be 32.6 feet (see Section 2.1.3). A line will be drawn through this point and perpendicular to the drawdown axis, until it intersects the curve. The discharge coordinate of the point of intersection will give the estimated target discharge rate for the constant-discharge test.

These procedures for estimating the target discharge rate for the constant-discharge test are based on the theory of superposition. A brief discussion of the theory of superposition, as it relates to water-level variations during step-drawdown tests in confined aquifers, can be found in Freeze and Cherry (1979).

The following example is intended to further illustrate the analysis procedures described above. In the example, the target drawdown is 21.0 feet, and the planned duration of the constant-discharge test is 48 hours. The corrected drawdown in the pumping well versus the logarithm of elapsed time is diagrammed schematically in Figure 1. This figure also includes a plot of the discharge rate versus time. Figure 1 graphically illustrates the relationship between the incremental drawdown values for the various steps of the test (see procedure 4 above).

Table 1 presents a summary of the results that would be obtained upon analysis of these data. The pump discharge rates for the various steps, which would have been measured during the test, are also included in the table. Figure 2 shows the discharge-versus-adjusted-drawdown plot corresponding to t = 48 hours. In this example, the target discharge rate is approximately 15.7 gpm (see procedure 6 above).

4.3 Analysis of Constant-Discharge Test Data

Corrected water-level data from the pumping test will be analyzed using standard aquifer test analysis methods. Corrected drawdown data will be plotted on log-log and semi-log scales. These plots will be used as a diagnostic tool to assess the type of aquifer system present and to select the proper model for data analysis. The log-log and semi-log plots will be compared to theoretical time-drawdown plots (or models) for various types of aquifer systems. Comparison of corrected drawdown plots of Pier 91 data with model drawdown plots for confined, unconfined, and leaky aquifer systems will allow the selection of the appropriate analysis method(s). Selection of an analysis method prior to collecting the test data requires assumptions that may not be appropriate and can result in an incorrect interpretation of the type of aquifer system present, as well as erroneous hydraulic parameter calculations.

Available data indicates the lower aquifer should behave as a confined or a leaky aquifer. If the drawdown data indicates that the aquifer is confined, either the Theis (Theis, 1935) or Cooper-Jacob (Cooper and Jacob, 1946) methods, or both may be used to calculate hydraulic parameters. If the aquifer response is characteristic of a leaky aquifer, either the Hantush and Jacob (Hantush and Jacob, 1955) or Hantush (Hantush, 1960) method will be used. The Hantush method accounts for storage in the aquitard, while the Hantush and Jacob method does not.

For the purpose of evaluating the degree of hydraulic connection between the shallow and deep aquifers, the water-level response of the shallow-aquifer monitoring wells will be compared to that of the deep-aquifer wells. An attempt will be made to explain the observed differences and similarities using conventional porous medium flow theory.

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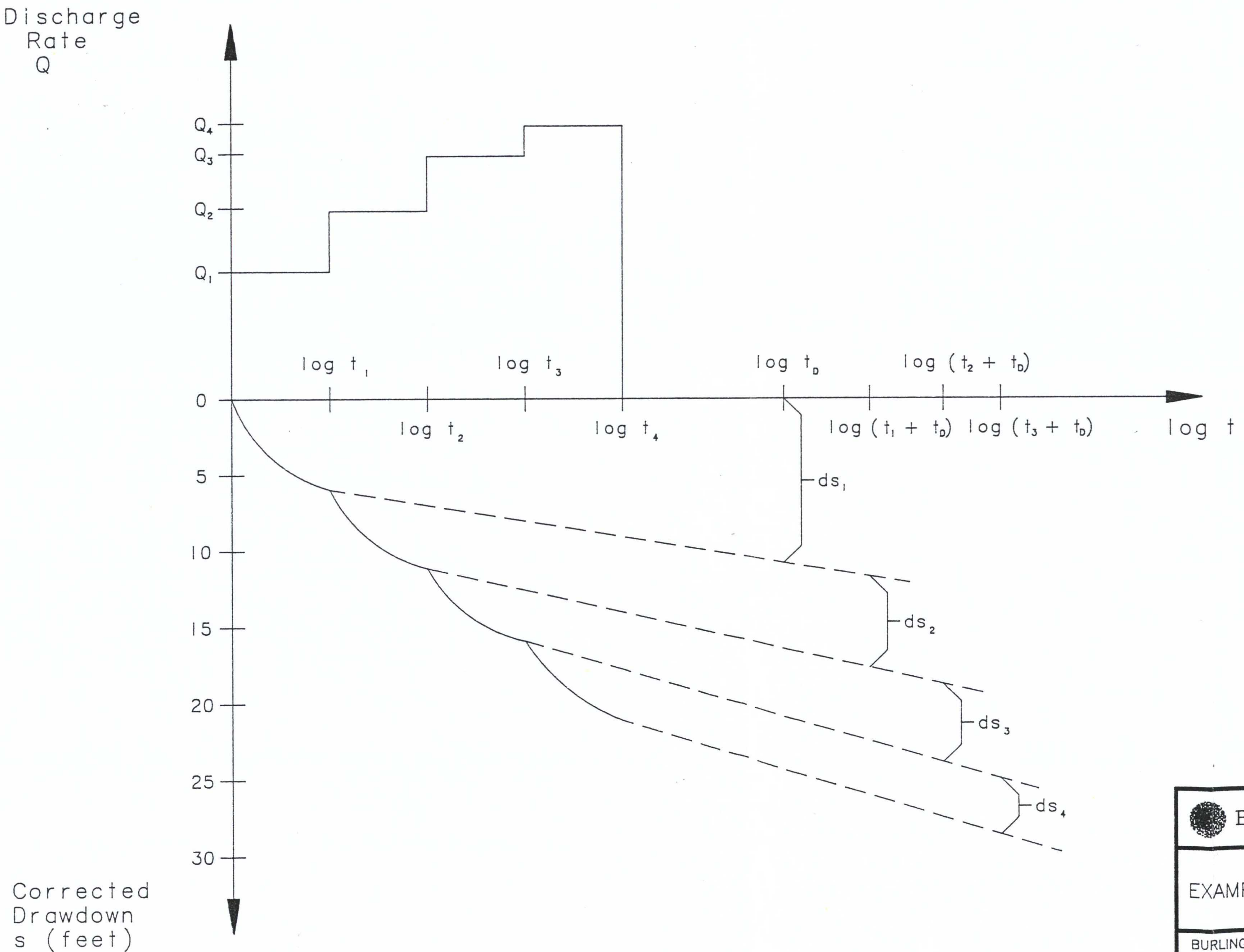

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EXAMPLE CORRECTED DRAWDOWN DATA

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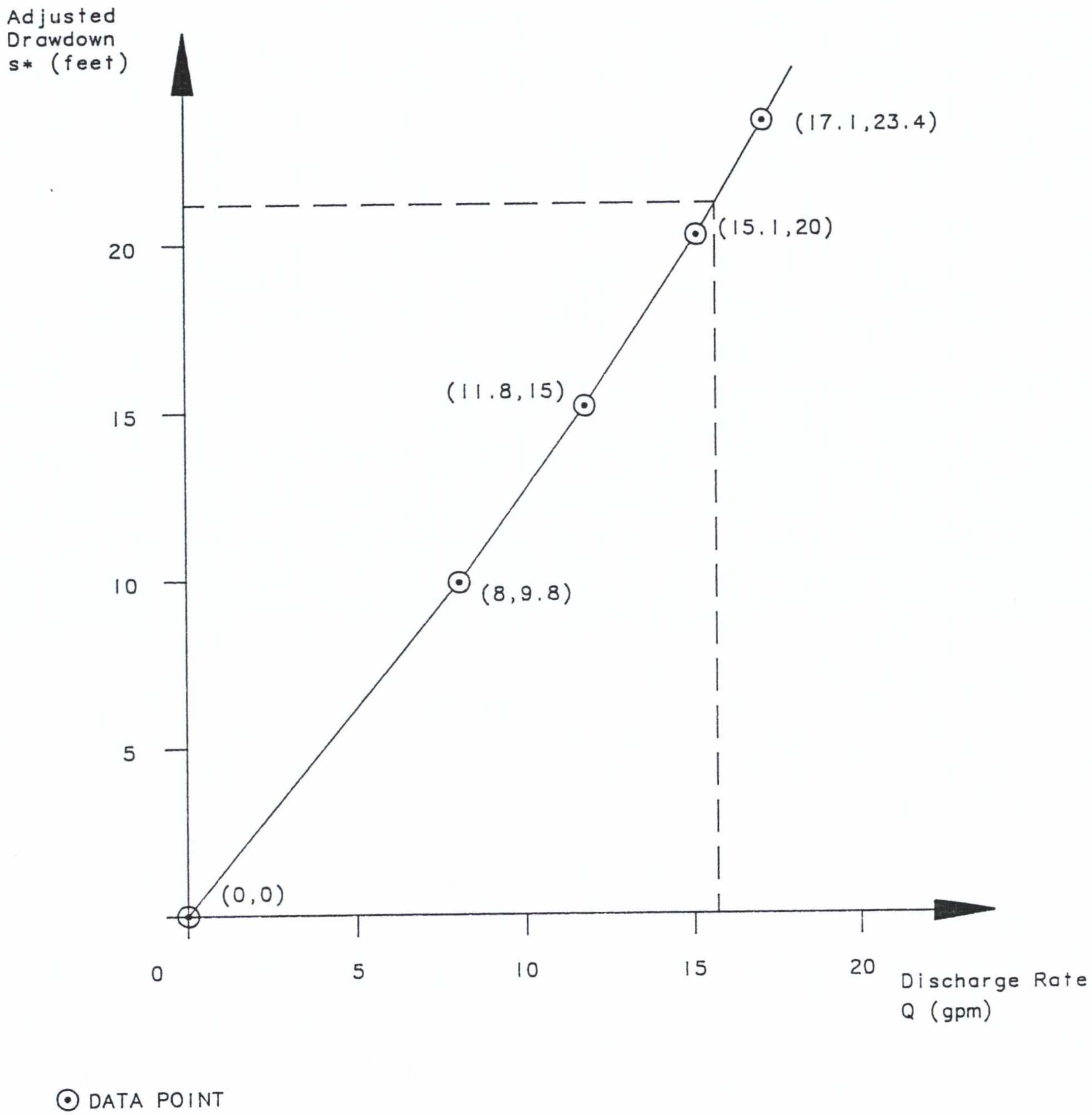
FIGURE 1

Table 1

SUMMARY OF RESULTS FOR EXAMPLE DESCRIBED IN TEXT

STEP	DISCHARGE RATE	INCREMENTAL DRAWDOWN	ADJUSTED DRAWDOWN AT 48 HOURS
i	Q_i	ds_i	s_i*
---	gpm	feet	feet
0	0.0	0.0	0.0
1	8.0	9.8	9.8
2	11.8	5.2	15.0
3	15.1	5.0	20.0
4	17.1	3.4	23.4



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EXAMPLE ADJUSTED DRAWDOWN vs. DISCHARGE, t=48 HOURS

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FIGURE 2

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5 REPORTING

After the constant-discharge pumping test is completed and all of the pertinent data have been collected, tabulated and analyzed, Burlington will prepare a written report on the test. The report will describe field procedures followed during both the step-drawdown and constant-discharge tests, list raw data collected during the tests, discuss other findings and observations, describe calculations used in the data interpretation, and present conclusions. The report will be completed within 45 days of completion of the constant-discharge test. If at that time the draft RFI report has not yet been submitted to the USEPA, the pumping test report will be included as part of the draft RFI report. Otherwise, the pumping test report will be submitted to the USEPA as an addendum to the draft RFI report.

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